Report as of FY2009 for 2009GU164B: "Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM"

Publications

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Report Follows

PROJECT SYNOPSIS REPORT

Project Title: Prediction of Flow Duration Curves for Use in Hydropower Analysis at Ungaged Sites in Pohnpei, FSM

Problem and Research Objectives

The cost and availability of energy resources is one key factor in the economic development and quality of life in any developing country. This is especially true in Pohnpei, Federated States of Micronesia (FSM), where nearly all of the energy produced is from costly, non-renewable, and potentially environmentally damaging fossil fuel (oil) resources. The cost of fuel to operate the local power plant has risen dramatically over the past years and no doubt will continue to rise in the future. With these increases of fuel costs, it becomes more and more important to explore other means of providing energy to the island's power grid.

Pohnpei is blessed with an abundance of surface water resources and because of the extreme topography of the island many of these streams have very high slopes. This combination of abundant streamflow and high stream gradient or slope is ideal for the application of run-of-river-hydropower development. This kind of hydropower development has the least environmental impact and is generally less capital intensive than typical hydropower plants built in conjunction with high dams with large amounts of water storage.

In order to explore the feasibility of using hydropower as an additional energy source for Pohnpei, it is necessary to be able to define the variability of flow available in the streams where the hydropower plants might be constructed. This is normally done by direct analyses of streamflow data for the stream in question or by applying some sort of inferential techniques from a gaged to an ungaged streams or from a gaged location on a stream to an ungaged location on that same stream. Of course, the most reliable means is to use actual stream flow data measured at the point of interest. The problem in Pohnpei, as in most locations, is that stream flow information is not available for all possible sites where development could occur. In the FSM this problem is even more acute since the streamflow gaging network has been abandoned for almost 30 years. The overall objective of this project is develop flow durations curves for reaches of Pohnpei's streams. These flow duration curves will be essential for studying future hydropower development in the streams. It will also be useful in making studies of low flow requirements and availability of water for various surface water developments and the study of the impacts of mans activities on stream flows. The project's goals were: to develop flow duration curves for all of the previously gaged stream sites in Pohnpei, to apply techniques for transferring the flow duration curve information available at the gaged locations to ungaged sites, divide Pohnpei's streams into homogenous stream reaches with similar flow characteristics, to develop flow duration tables and curves for each stream reach, to develop a set of GIS based maps showing the location of all stream reaches, and finally to provide sample calculations of power potential and economic feasibility of several potential hydropower sites on Pohnpei.

Methodology

This project was divided into several phases that are described below.

PHASE I, Develop Flow Duration Curves for Each Gage Site

The first step was to gather all the available daily streamflow data for Pohnpei's streams into computer spreadsheet form. This was accomplished using the Water and Environmental Research Institute's (WERI's) Earth Info CD-ROM data base and accompanying data accessing programs. Figure 1 shows the location of the United States Geological Survey (USGS) stream gage sites that were used in the study. Figure 2 provides information on the period of record for each of the gages.

A spreadsheet program developed specifically for use on this project assigned each of the daily flows into flow range categories specified by the user. The number of daily flow values greater than or equal to the upper limit of each category was then calculated. This value was divided by the total number of flows to find the percent of daily flows greater than or equal to the highest flow in that category. This term is called the exceedance percentage. A flow duration curve that shows the flow versus the exceedance percentage was plotted for all Pohnpei's gage sites as shown in Figure 3.

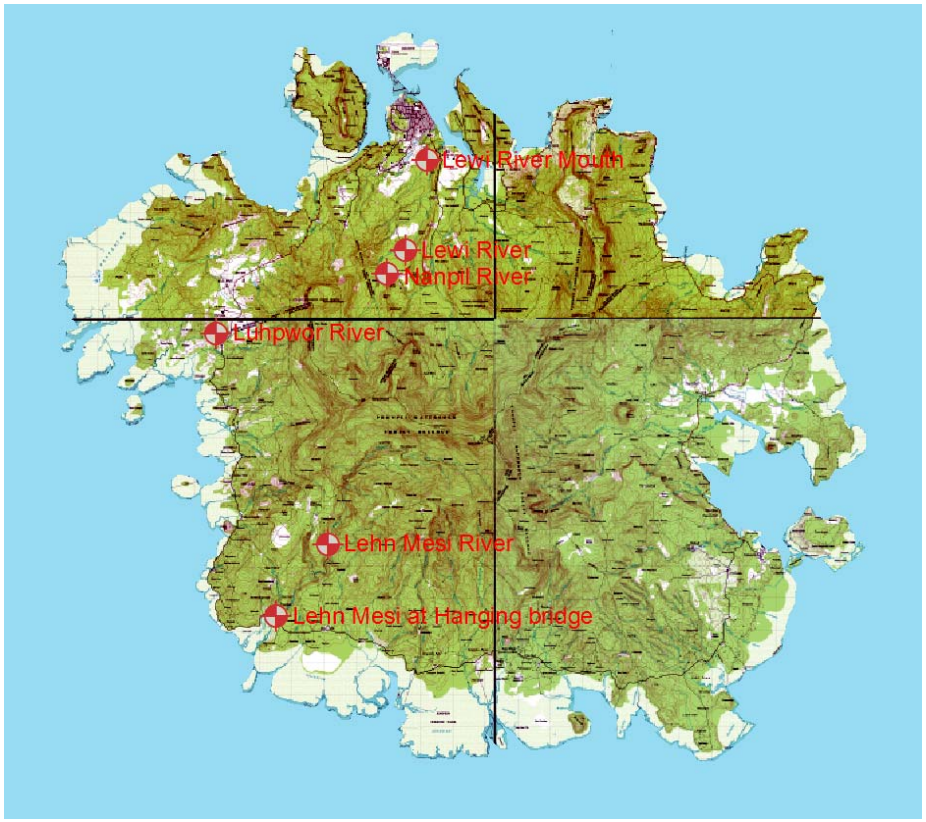

Figure 1. Location of USGS stream gage sites

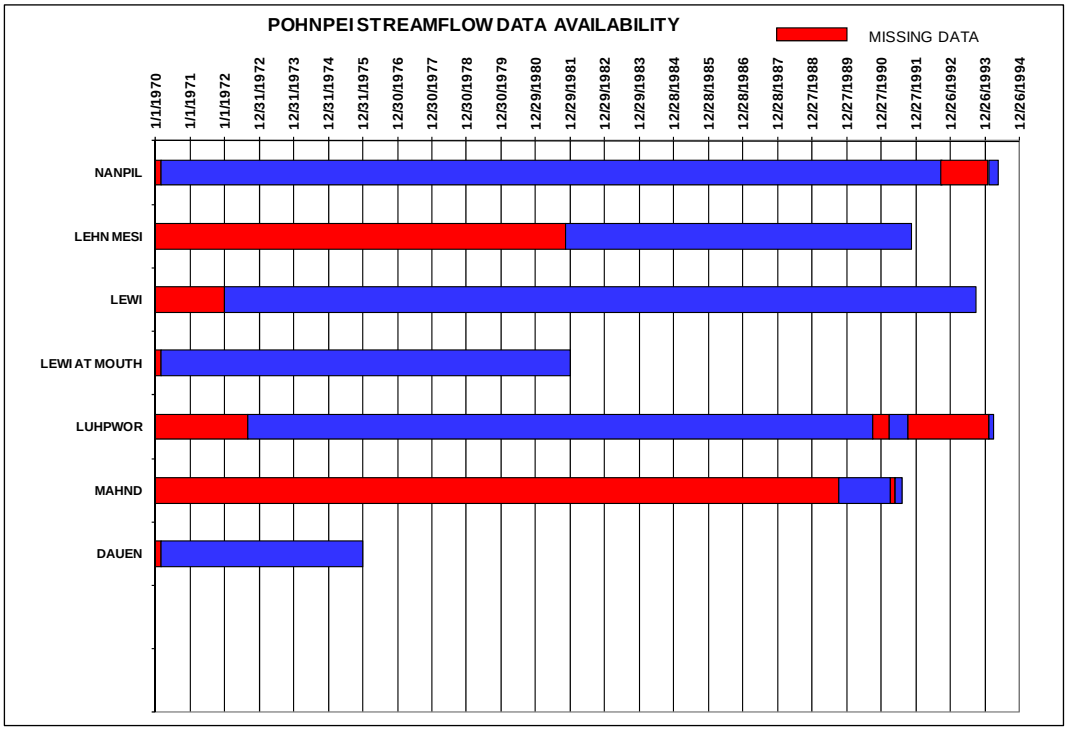

Figure 2. Availability of stream flow data from USGS gages on Pohnpei

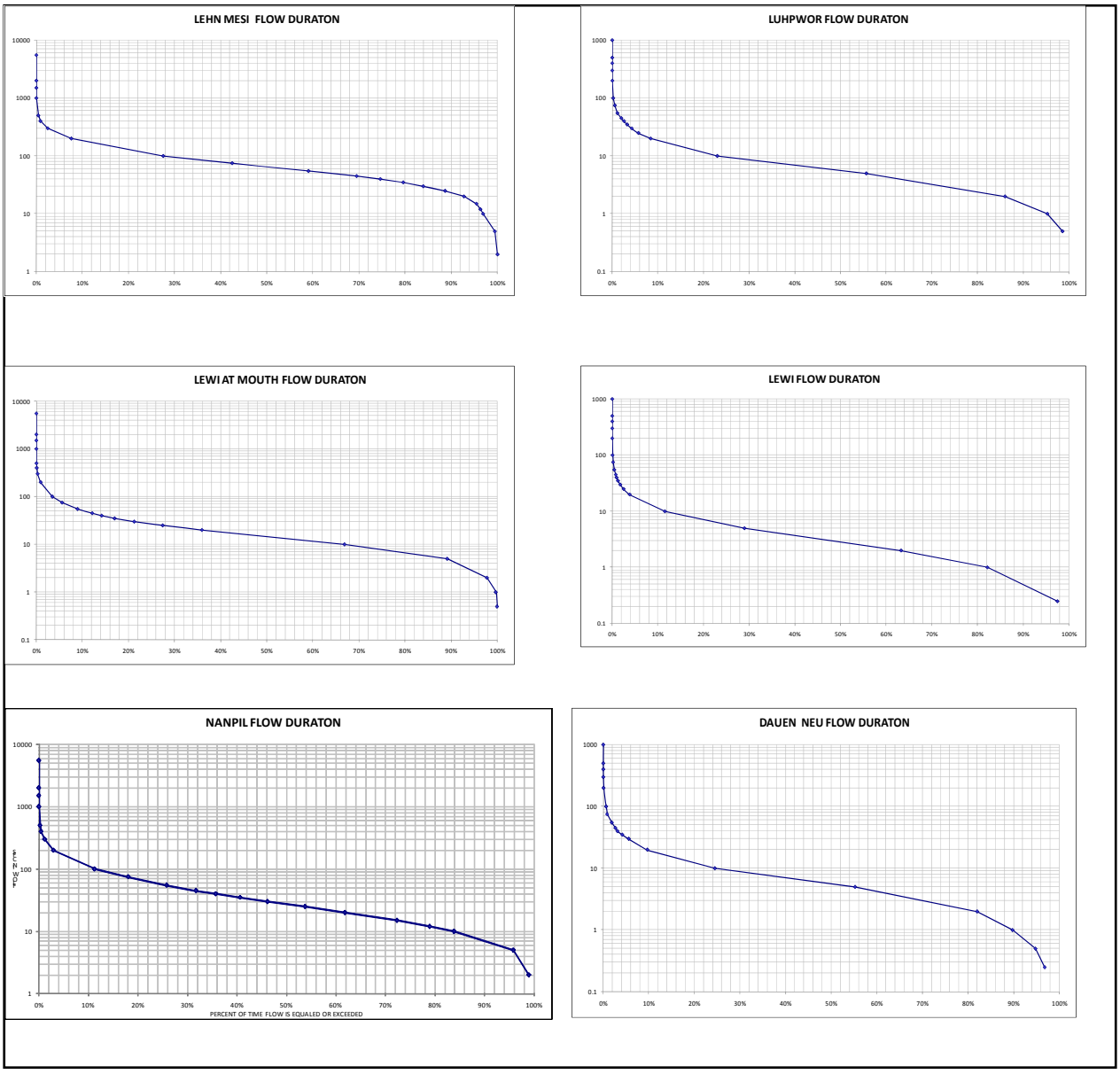

Figure 3. Duration Curves for Nanpil, Lehn Mesi, Luhpwor, Lewi at Mouth, Lewi, and Dauen Neu Rivers

PHASE II, Prediction of Duration Curves at Ungaged Sites

Phase II involved the application of a technique to predict duration curves at ungaged sites in Pohnpei. This step is important because many of the potential hydropower sites in Pohnpei are not located at or near stream gage locations. Some may be located upstream or downstream from gagged location and some may be located on streams where no previous stream flow records are available. The method that was applied involved the development of parametric curves of flow versus average annual flow for chosen specific exceedance percents. This method was originally developed by the co-

investigator in a study of hydropower potential in the Pacific Northwest. (Gladwell, et al, 1979).

The first step in applying the method was to take the flow values for the key exceedance percentages of Q(95), Q(30), Q(50), and Q(30) from each of the duration curves developed in Phase I. These particular exceedance values were chosen because these percentages are important in the sizing of hydropower plants. Next the average annual flow was computed for each site. The values of Q vs Average Annual Flow were plotted for each exceedance value at each site and a best fit curve was matched to the data sets. The resulting parametric curve is shown in Figure 4.

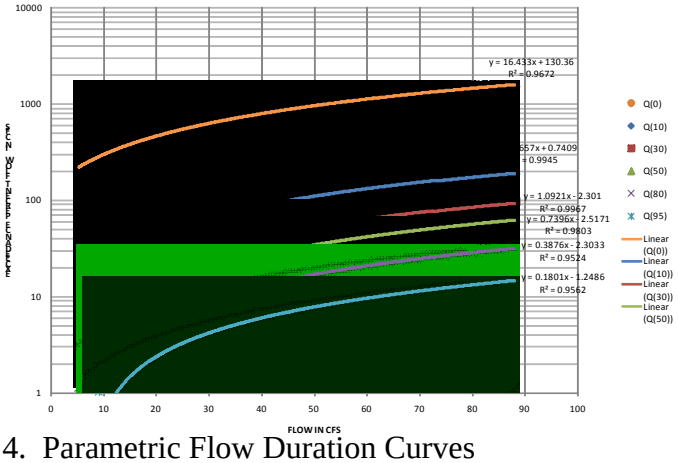

Figure 4. Parametric Flow Duration Curves

The best fit equations are shown at the end of the curves for each exceedance percentage. Although there were limited number of data points the high R^2 values indicates a very good fit to the data by the prediction equations. These equations were used later to predict actual flows at ungaged sites or stream reaches. Figure 5 shows an example of using the ungaged curves to predict the flow duration cure values for an ungaged site with an average annual flow of 60 cfs.

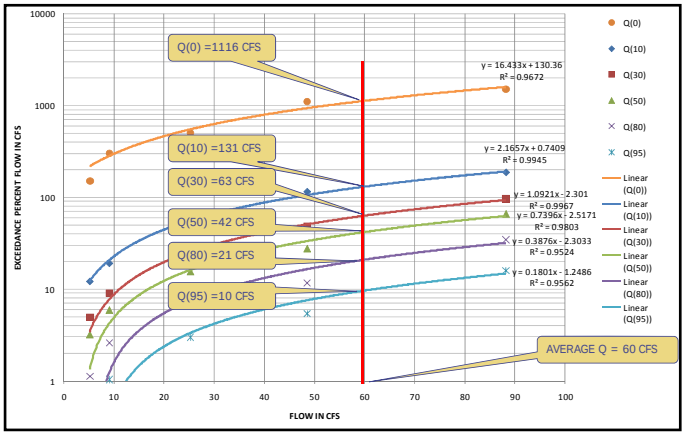

Figure 5. Use of parametric flow duration curves to predict flow duration values at an ungaged site with an average flow of 60 cfs

PHASE III, Develop a Means to Predict Average Flow at Ungaged Points on Streams

In Phase III we developed a means to predict average flows at ungaged points on Pohnpei's streams. The technique called for the development of grid based maps of elevations and average annual rainfall and then applying various GIS Watershed functions available in the computer program ArcMap. The end product was a grid based map of average rainfall input for the streams in Pohnpei. Since, not all the rainfall reaches the stream due to the losses in the hydrologic system; a correction factor called "Runoff Factor, RF" was employed. The RF factor was developed for gaged streams as shown in Figure 6. A best fit curve was developed as shown so that runoff factors at ungaged sites could be predicted. These factors were multiplied by the GIS predicted rainfall input to determine the average annual flow for ungaged locations. Next the predicted average flow for ungaged sites were inputted into the parametric flow duration curves (Figure 4) in order to predict flow duration curves for ungaged sites. More detail on procedure is reported in (Heitz, Khosrowpanah, 2010).

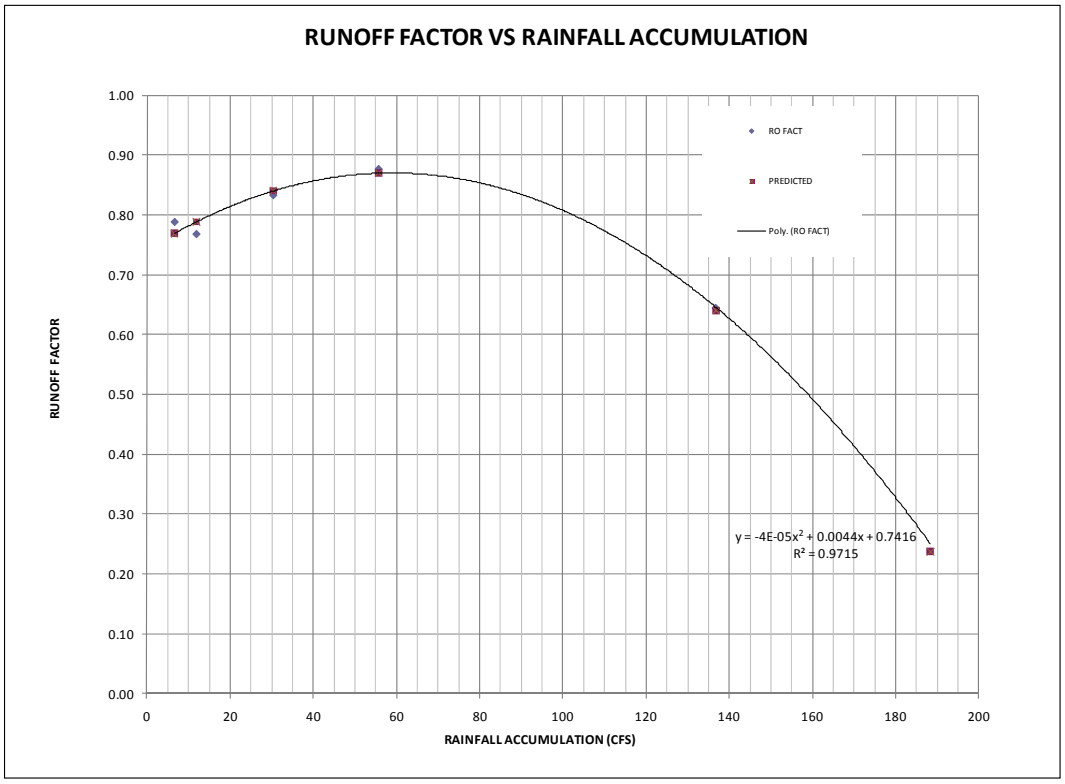

Figure 6. Runoff factor vs rainfall accumulation

PHASE IV, Stream Reach Delineation and Average Flow

In Phase IV we divided Pohnpei's streams into homogenous stream reaches with similar flow characteristics (small pieces of watershed that contributes to each tributary of the major stream within the watershed). This mapping was done starting with the USGS's Digital Line Graphics (DLG) hydro-coverage available for the USGS Topographic Maps. Substantial editing was required on the Hydro DLGs to develop a good coverage showing

only the streams. Figure 7 shows an actual stream reach on the Lehn Mesi River as an example.

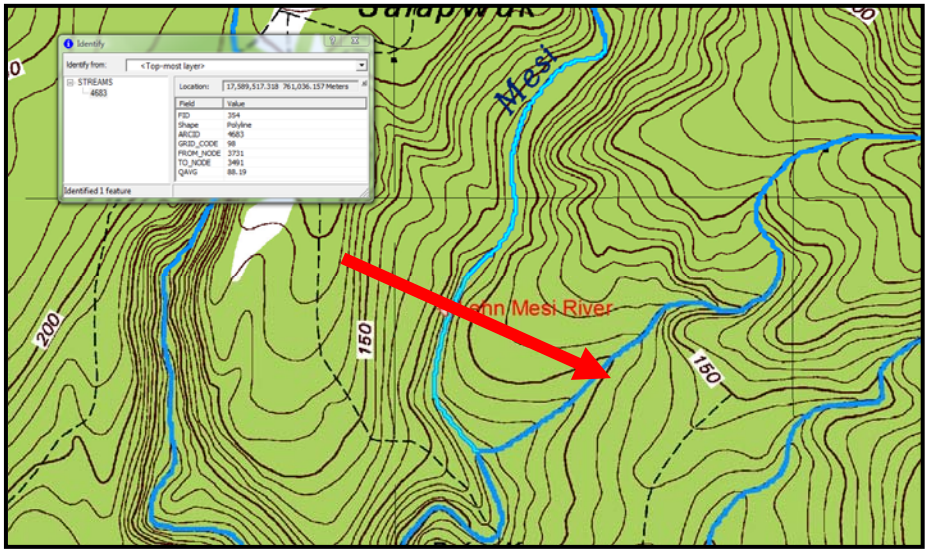

Figure 7. Individual stream reach on the Lehn Mesi River

PHASE V, Hydro Power Production and Economic Analysis

In this Phase of the work a means of calculating the power potential and economic feasibility of potential hydropower sites in Pohnpei was developed. A previously developed spreadsheet program (Heitz, 1982) was used as a basis for the new hydro power potential Excel application. The first worksheet of the application is shown in Figure 8. Input to this sheet is the potential site's average annual flow which comes from the previously described GIS maps. The application computes the flow duration values using the parametric duration curves described earlier. The application also plots the flow duration curve for the selected site. The second worksheet of the application, shown in Figure 9, computes the power production and economics of the site based on the flow duration curves computed on the first worksheet and the input site head, turbine sizing information and economic considerations. This application will allow the user to explore various turbine sizing and economic considerations to determine the preliminary feasibility of developing a hydropower facility at a particular site. A copy of the Excel Workbook will be furnished to those interested in carrying out their own analysis at other sites in Pohnpei.

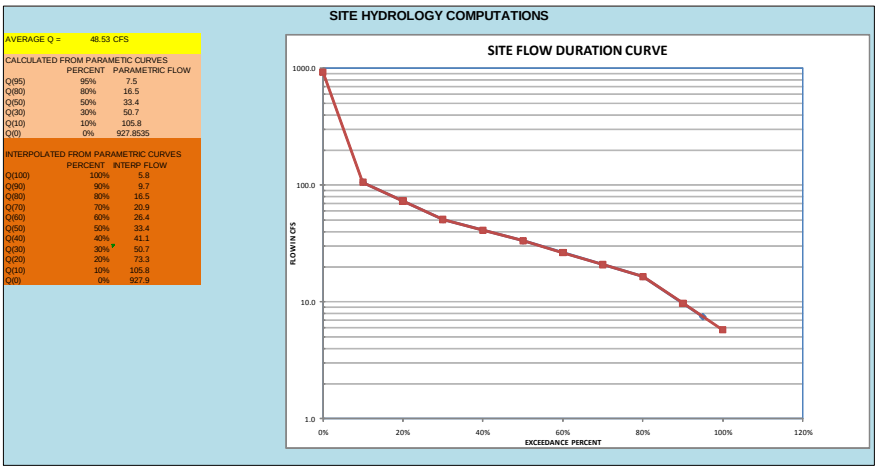

Figure 8. Hydrology worksheet of hydropower analysis application

TURBINE SIZING RECONNAISSANCE PACKAGE
BY DR. LEROY HEITZ P.E.

TURBINE PARAMETERS

	DESIGN	MINIMUM	MAX EFF (%)		FLOW RATIO	EFFICIENCY RATIO
Q TURBINE 1=	4	3.2	0.83	1.	0	0
Q TURBINE 2=	4	3.2	0.83	2.	0.6	0.7
Q TURBINE 3=	4	3.2	0.83	3.	0.8	0.8
				4.	0.9	0.95
GENERATOR EFFICIENCY=	0.9			5.	1	1

OTHER DESIGN PARMETERS

COMPUTATIONAL PERIOD =	365	DAYS
PENSTOCK LENGTH =	8000	FT
STREAM MINIMUM Q =	1	CFS

AVAILABLE FLOW AND HEAD / **POWER PRODUCTION**

EXCEED	STREAM FLOW	GROSS HEAD	AVAIL FLOW	FLOW TURBINE 1	FLOW TURBINE 2	FLOW TURBINE 3	FLOW UNUSED	POWER TURBINE 1	POWER TURBINE 2	POWER TURBINE 3	POWER TOTAL	ENERGY TOTAL
%	CFS	FT	CFS	CFS	CFS	CFS	CFS	KW	KW	KW	KW	MWH
100	2.00	800.00	1.00	0.00	0.00	0.00	1.00	0	0	0	0	
90	3.50	800.00	2.50	0.00	0.00	0.00	2.50	0	0	0	0	0.00
80	4.50	800.00	3.50	3.50	0.00	0.00	0.00	142	0	0	142	62.03
70	6.00	800.00	5.00	4.00	0.00	0.00	1.00	192	0	0	192	146.22
60	8.00	800.00	7.00	4.00	0.00	0.00	3.00	192	0	0	192	168.37
50	10.50	800.00	9.50	4.00	4.00	0.00	1.50	192	192	0	384	252.55
40	15.00	800.00	14.00	4.00	4.00	4.00	2.00	192	192	192	577	420.92
30	22.00	800.00	21.00	4.00	4.00	4.00	9.00	192	192	192	577	505.11
20	27.50	800.00	26.50	4.00	4.00	4.00	14.50	192	192	192	577	505.11
10	27.50	800.00	26.50	4.00	4.00	4.00	14.50	192	192	192	577	505.11
0	27.50	800.00	26.50	4.00	4.00	4.00	14.50	192	192	192	577	505.11
											SUM E =	3070.54

ECONOMICS COMPUTATIONS

ECONOMIC INPUTS

COST TURBINE 1 =	$1,000	$/KW	**BORROWING PERIOD =**	30 YRS
COST TURBINE 2 =	$1,000	$/KW	**INTEREST RATE =**	12 %
COST TURBINE 3 =	$1,000	$/KW	**CONSTRUCTION PERIOD =**	1 YRS
PENSTOCK COST =	$100	$/FT	**TAXES =**	3.5 % 1st COST
OTHER COSTS =	$50,000	$	**INSURANCE =**	0.15 % 1st COST
ENERGY VALUE =	$0.10	$/KWH		
CAPACITY BENEFIT=	$100	$/KW		

ECONOMICS RESULTS

FIRST COSTS		ANNUAL COSTS		ANNUAL BENEFITS	
TURBINE COST =	$606,957	**INTEREST AND PRINCIPLE=**	191,724	**ENERGY BENEFIT =**	$307,054
PENSTOCK COST =	$800,000	**TAX COST =**	50,994		
OTHER COST COST =	$50,000	**INSURANCE COST =**	2,185	**CAPACITY BENEFIT =**	$60,696
CONSTRUCTION INTEREST =	$87,417	**O&M COST =**	13,115		
TOTAL COST =	$1,544,375	**TOTAL ANNUAL COST =**	**258,019**	**TOTAL NET ANNUAL BENEFIT =**	**$367,749**
ANNUAL COST =	$191,724			**NET BENEFITS =**	**$109,731**
				B/C =	**1.425**

Figure 9. Hydropower output, turbine sizing and economic feasibility worksheet of hydropower analysis application

Principal Findings and Significance

This study provided a means to evaluate the hydroelectric potential at sites and on reaches of streams in Pohnpei, FSM. In order to accomplish this, average flows were developed for stream reaches on all Pohnpei's major streams. A means of computing flow duration curves from these average flows was also developed.

A spreadsheet application is provided in which average flows are input along with various hydraulic and economics parameters. A power potential and economic analysis is then performed. This analysis provides preliminary estimates of the feasibility of developing a hydroelectric project at a particular site. The spreadsheet is available as part of the data package for this project.

The average flow data is made available through a GIS map of the stream reaches on all the major streams on Pohnpei. The data for this map is available for use with the free GIS application Arc Explorer. This average flow data is useful for other applications beyond just estimating hydroelectric potential. When coupled with the hydrology worksheet in the spreadsheet application, flow duration curves can be estimated for any stream in Pohnpei. This information could be used for in stream flow requirement studies or other studies investigating man impact on the natural flow patterns in the streams.

LITERATURE CITED

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Khosrowpanah, S, and Mark Lander, and L. Heitz, “Pohnpei-the wettest island on earth? Tools for managing watershed”, Proceeding of the Institutions for sustainable watershed management, American Water Resources Association, Honolulu, Hawaii, June 27-29, 2005.